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Interpretation of an Aeromagnetic Survey in Western Pennsylvania and Parts of Eastern Ohio, Northern West Virginia, and Western Maryland

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ABSTRACT

Interpretation of the U. S. Geological Survey aeromagnetic map GP-445 indicates a number of basement relief features superimposed on the regional southeasterly slope of the basement surface. These basement relief features seem to be unrelated to known Paleozoic structures and may be of economic importance by their influence on the oil potential of the overlying sediments. A basement structure contour map is presented.

INTRODUCTION

During the summer of 1960 the U. S. Geological Survey conducted an aeromagnetic investigation of an area comprising much of western Pennsylvania and contiguous portions of Maryland, Ohio, and West Virginia (see figure 1). The information resulting from this survey, which was carried out under the direction of A. J. Petty, has been compiled and released in the form of a contoured aeromagnetic map (Popenoe and others, 1964).

The surveyed area lies just west of the folded Appalachians. Topographically it consists of a series of dissected plateaus, developed by erosion of a sequence of gently folded sedimentary rocks which range in age from Devonian to Permian. Pre-Devonian sedimentary rocks are known to occur in the subsurface; for instance, the Jessie C. Hockenberry Number 1, a gas well drilled in Butler County, Pennsylvania, penetrated more than 10,000 feet of sandstone, carbonate rock, shale, and evaporite deposits before bottoming in the Gatesburg Formation of Late Cambrian age (Fettke, 1956, Plate 2). In general, structural and topographic relief are greatest in the southeastern sector of the area.

* Publication authorized by the Director, U. S. Geological Survey.

The surveying technique, in brief, was as follows. A series of 128 lines, each approximately 120 miles in length and spaced at one mile intervals, were flown in a north-south direction across the area, while the change in total intensity of the earth's magnetic field was recorded continuously on a modified AN/ASQ-3A magnetometer. During flight the aircraft was maintained at an elevation of approximately 500 feet above the ground. Several east-west lines also were flown, in order to permit compensation for diurnal magnetic variation and instrumental drift.

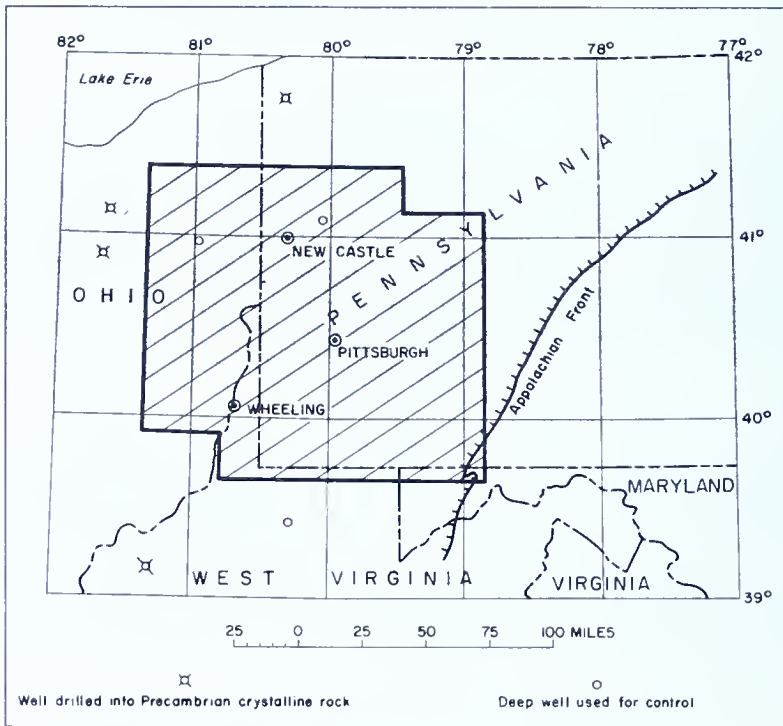


Figure 1. Index map showing area of aeromagnetic survey and wells used for control

AEROMAGNETIC MAP

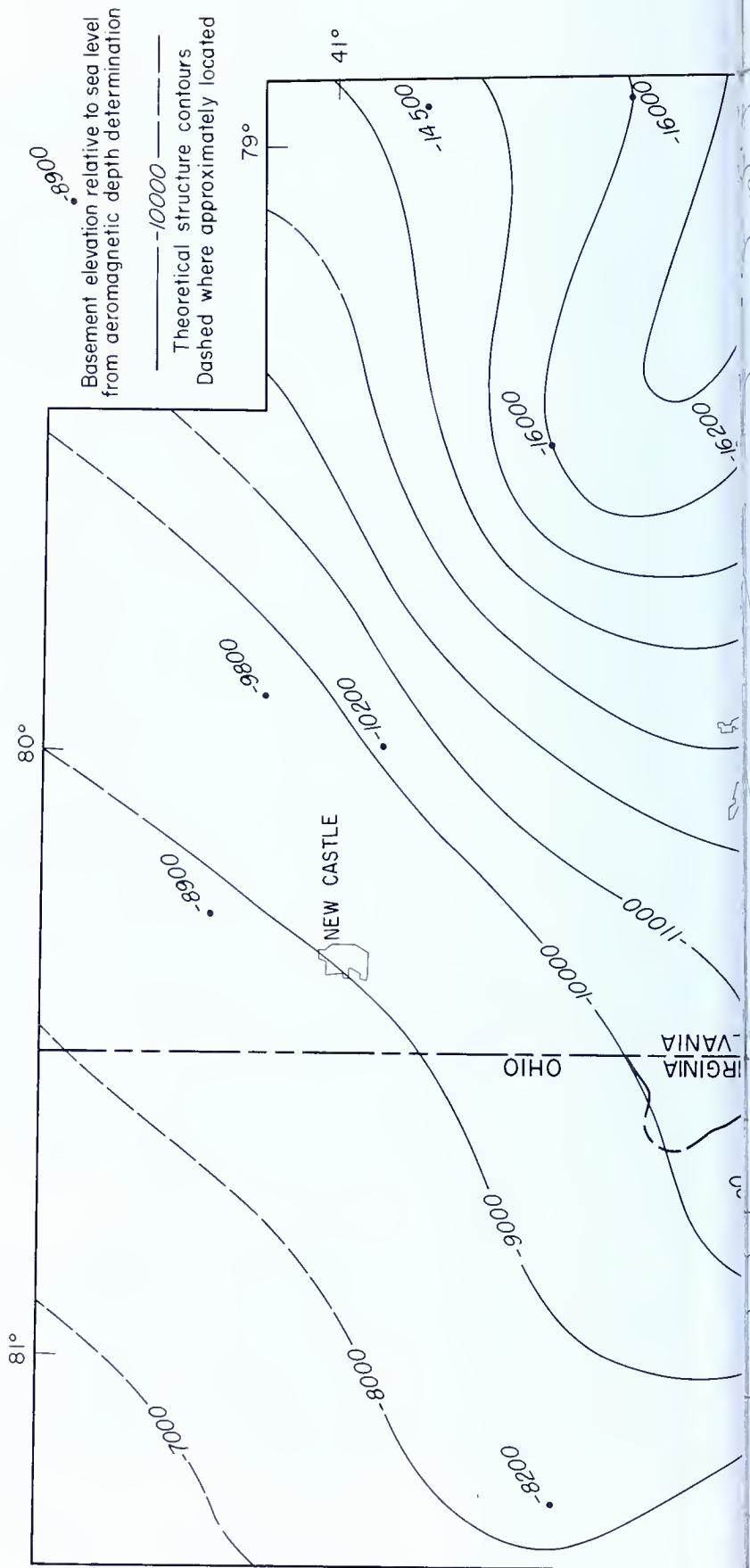
The Paleozoic sedimentary rocks underlying the surveyed area are almost wholly nonmagnetic with respect to their influence on the local geomagnetic field. A possible exception is the Clinton Formation, consisting of Middle Silurian elastic deposits which in places contain zones sufficiently rich in hematite to serve as iron ore. Hematite, however, is a weakly magnetic mineral, and thin semi-continuous sheets of even

relatively concentrated hematite ore buried beneath many thousands of feet of sedimentary rocks seem unlikely to have much magnetic effect at the Survey elevation.

In contrast, the magnetization of the crystalline basement rocks underlying this sedimentary sequence probably contributes heavily to the changes in intensity of the geomagnetic field which have been recorded as anomalies on the aeromagnetic map. Basement rocks are not exposed within the area of the survey, nor have they been encountered in drill holes. In surrounding areas, however, Precambrian crystalline rocks composed of a varied suite of metamorphosed sedimentary and igneous materials, intruded by igneous bodies with diverse lithologic and magnetic properties, are known to occur beneath the Paleozoic rocks. Such a terrain may be likened to a mosaic of relatively large, magnetically homogeneous blocks, for the most part extending to depths great in comparison to their distance beneath the airborne magnetometer. Moreover, in many cases sharp magnetic contrasts are present across the boundaries of these blocks. Thus, the aeromagnetic map probably reflects the distribution, depth, shape, and magnetic properties of the various units within the crystalline basement, with little, if any, contribution from the overlying sedimentary material.

Basement topographic relief also may give rise to magnetic anomalies. However, in areas of thick sedimentary cover, the magnetic contribution of this factor tends to be small, for the most part being masked by large anomalies originating in lithologic contrasts within the basement (Vacquier and others, 1952, p. 8). Basement topographic relief probably accompanies many such lithologic contrasts, arising from structure. Precambrian differential erosion, or the presence of late intrusions penetrating the sedimentary column. Magnetic anomalies in such cases are a composite of the effects of lithology and topography, with the former greatly predominant. Methods of depth estimation, one of which is discussed in the following section, provide a direct approach to the question of basement topography.

The trends of these magnetic units, and the sense of elongation of a number of other anomalies in the eastern part of the area, define a pattern or magnetic grain which probably reflects the orientation of structural axes within the Precambrian crystalline complex. If so, there is a slight but systematic divergence, averaging 10 to 15 degrees, between Precambrian and Paleozoic structural trends within the surveyed area, the Precambrian axes having the more northerly orientation. Apparently



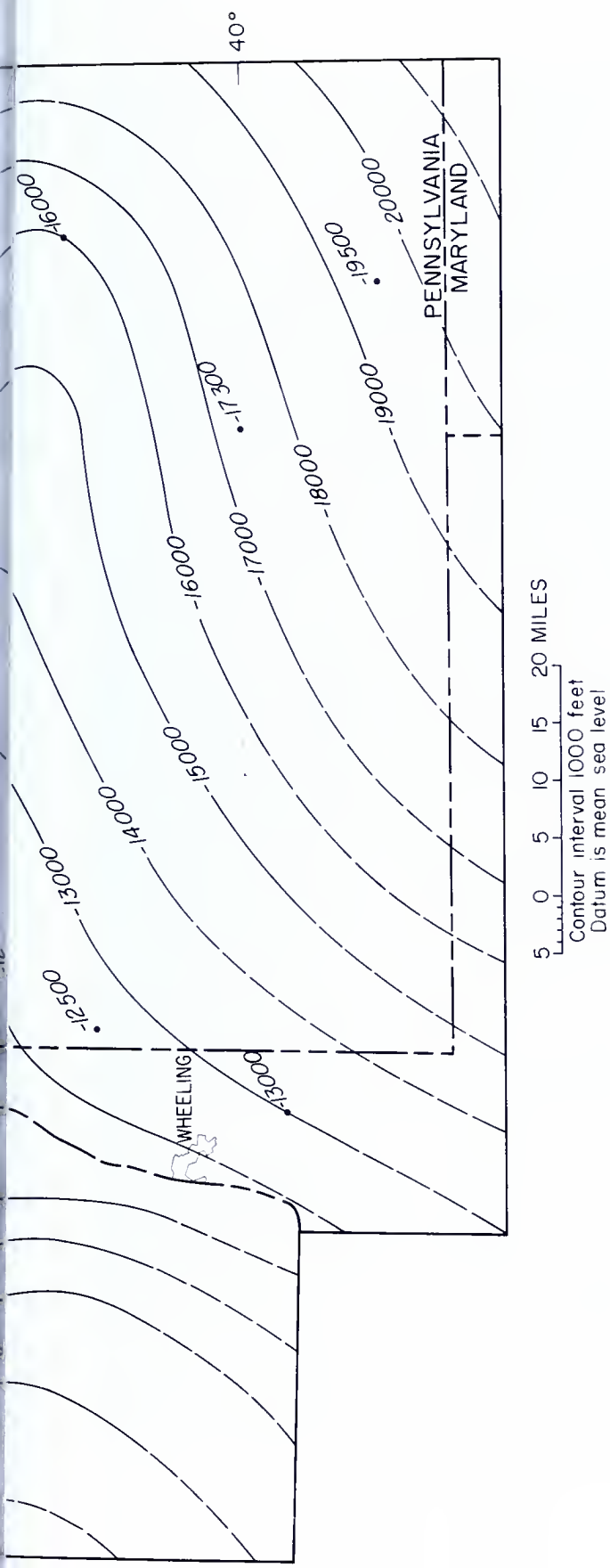


Figure 2. Theoretical structure contours on crystalline basement in western Pennsylvania, and portions of Ohio, Maryland and West Virginia based on aeromagnetic data.

structures developed in the Precambrian rocks prior to the onset of Paleozoic sedimentation were able to survive deformation of the Appalachian geosyncline.

BASEMENT CONTOUR MAP

The distance separating the source of an anomaly from the magnetometer exerts a controlling influence on the curvature of measured magnetic gradients. For example, a mafic plug intruding nonmagnetic sediments might give rise to a sharp, steep-sided, high-amplitude anomaly if its top extended to within 1000 feet of the magnetometer, whereas the same body would produce a much broader feature of lower amplitude if buried to a depth of 10,000 feet. This relationship between anomaly slope and depth of burial provides the basis for a system of depth estimation (Vacquier and others, 1951) designed to aid in the interpretation of aeromagnetic maps, especially those of regions where anomaly sources are not exposed.

Briefly, this method consists of the comparison of a set of theoretical anomalies with those recorded during the aeromagnetic survey. Hypothetical anomalies have been calculated for 83 bodies, assuming differences in their size, shape, and orientation and in the inclination of the earth's magnetic field. These bodies are further assumed to take the form of bottomless rectangular prisms, with vertical sides, a horizontal upper surface, and a uniform magnetization directed along the earth's magnetic field. As rock masses answering these specifications rarely, if ever, are encountered in nature, the reliability of the method hinges on its insensitivity to minor deviations from these ideal conditions. Vacquier and others (1951) have given reason to believe that this insensitivity exists, and experience has tended to confirm the essential accuracy of the method if care is exercised in the selection of anomalies for analysis (see, for instance, Henderson and Zietz, 1958, p. 29).

Depths to magnetic basement may be obtained rapidly and easily by this technique. First, from a careful study of the map, an anomaly is selected which appears to be a reflection of a single magnetic unit; complicated anomalies characterized by the interference of two or more magnetized bodies must be avoided. Next, the horizontal extent of the steepest magnetic gradient defining this anomaly is measured on one or more of its flanks. Using this figure (or an average of several such figures) as a first approximation of the body's depth, the size of the magnetic unit is measured in terms of depth units, and its orientation with respect to

magnetic north is determined. These figures, together with the inclination of the earth's magnetic field, permit selection of the theoretical anomaly most appropriate for detailed comparison. As the latter have been plotted in terms of units of depth, the conversion of approximate to true depth becomes a straightforward operation. In general, it is preferable to choose the average of a number of determinations as the best available depth, especially since the scatter present in such a process can serve as a rough measure of the reliability of the estimate in question.

Application of this method to the aeromagnetic map resulted in fifteen calculated depths to magnetic basement. From three to nine separate profiles were used for each analysis; the average range of values for each individual anomaly was 25% of the mean. In the absence of drill holes to basement, one half the latter figure, or 12½%, perhaps may serve as the best available rough indication of the limits of reliability of the data. Because this figure refers to the depth of the anomaly beneath the aircraft, it represents a maximum uncertainty of approximately ± 2500 feet for the deeper determinations.

A basement contour map, Figure 2, has been prepared from these fifteen computed depths. Wells in adjoining areas were also utilized as control. Perhaps the map's most outstanding characteristic is a persistent southeasterly slope, averaging approximately 85 feet per mile, apparently recording the dip of the basement surface beneath the folded Appalachians. Superimposed on this regional slope are several undulations, in the form of a low ridge and fairly marked trough, both plunging to the southeast. These features seem to be unrelated to known Paleozoic structures, and also appear to lie athwart the Precambrian structural trend deduced from the aeromagnetic map. They may represent the remnants of a major Precambrian drainage system, drowned and buried during Paleozoic sedimentation. However, control for their trend is scanty and, as their amplitude is approximately equal to the maximum uncertainty inherent in the depth calculations, they should be interpreted with care.

Another prominent feature of the basement contour map is a well-defined break in slope which occurs along a zone coincident with the northeast-southwest diagonal of the surveyed area. This change in slope is least recognizable near the center of the map, but elsewhere is unmistakable. Reference to the aeromagnetic map reveals a steep, linear magnetic gradient of identical trend located near the same diagonal; moreover, this gradient also tends to lose its identity toward the center

of the area. Nothing definite can be said about this feature in the absence of more geophysical evidence or extensive drill-hole information, but the magnetic data seem to be recording either a significant basement structure, possibly a basement-fault; a major lithologic change, or perhaps a combination of the two.

ECONOMIC IMPLICATIONS

The interpretive technique used in constructing the basement map is at its best when applied to geologic problems of a regional nature. It furnishes estimates of total sedimentary thickness and basement configuration over broad areas, and thus is a valuable adjunct to regional stratigraphic and structural analysis aimed at the location of broad areas of potential petroleum accumulation. In general, it lacks the resolution necessary to define local sedimentary structures which might be of specific economic interest.

Two of the large basement features discussed above are nevertheless of potential interest to the petroleum industry. Either the possible basement fault or the plunging ridge, regardless of origin, may be accompanied by oil traps in the overlying sediments. Neither seems to be reflected in the known structure of the shallower stratigraphic horizons, but there is very little direct information pertaining to the pre-Devonian geology of the two areas. The evidence upon which these features are based is of inconclusive nature; nevertheless, they seem to merit close reexamination by more specialized interpretive techniques, possibly supplemented by additional geophysical investigations.

In certain cases aeromagnetic maps have proven reliable guides to exploratory drilling. For instance, closed anomalies may indicate a prominence rising above the basement surface; either an intrusion penetrating, and possibly arching, the overlying sediments, or residual crystalline "hills" over which draping and differential compaction of younger rocks might have occurred. In either case, petroleum accumulations might accompany such an anomaly. However, identical magnetic features also arise from lithologic changes within the basement, with no accompanying topographic high. In general, considerable ambiguity is inherent in the use of aeromagnetic techniques in the search for oil, some of which may be resolved by other geophysical means. A complete discussion of these complexities may be found in such standard textbooks on exploration geophysics as Heiland (1963).

SUMMARY AND CONCLUSIONS

The aeromagnetic map of southwestern Pennsylvania and neighboring areas presents a pattern of magnetic anomalies which probably originates within the crystalline basement. The eastern half of the area displays a distinct north-northeasterly to northeasterly lineation of magnetic anomalies, which appears to die out to the west and northwest. This lineation probably is a reflection of Precambrian deformational trends, recording the regional strike of magnetically contrasting lithologic units within the crystalline basement. If so, there seems to be a small but consistent divergence of Precambrian and Paleozoic structural axes within the plateau area of western Pennsylvania.

Analysis of the geometry, and especially the curvature, of certain anomalies facilitates estimates of the depth to their cause. Depths so obtained, when combined with a limited amount of well data, indicate that the surface of the crystalline complex in western Pennsylvania, although modified by transverse undulations and at least one major break in slope, maintains a gentle dip toward the folded Appalachians.

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